

## MONITORING THE EFFECTS OF AIR-QUALITY ON FORESTS: AN OVERVIEW OF THE SIERRA ANCHA EXPERIMENTAL FOREST ICP-LEVEL II SITE

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### ABSTRACT

The Sierra Ancha International Cooperative Program on Assessment and Monitoring of Air Pollution Effects on Forests study site or (SAEF-ICP II) is part of an international network of cooperative forest monitoring sites spread throughout Europe and the United States. The United Nations Economic Commission for Europe established the ICP II network in 1985 to monitor long-term effects of transboundary air pollution. The Sierra Ancha Experimental Forest was chosen to be a part the U.S.'s network because it is the southernmost Experimental Forest in the contiguous U.S., and because it is downwind from a major metropolitan area, Phoenix, Arizona. The site monitoring includes forest overstory growth, crown condition, foliar chemistry, understory vegetation, litterfall, soil chemistry meteorology, ozone, and deposition. This paper provides an overview of the ICP forest network, and discusses the research currently underway at the Sierra Ancha ICP II site. An overview of the challenges encountered while implementing ICP Level II monitoring will also be included.

### INTRODUCTION

#### Background: ICP Forest Monitoring

In 1985, the United Nations Economic Commission for Europe under the Convention on Long-range Transboundary Air Pollution established the International Co-operative Program on the Assessment and Monitoring of Air Pollution or ICP forest network in response to the deterioration of tree crowns observed across Europe attributed to air pollution. Research has shown the negative impacts of ozone and nitrogen deposition on forest health and site productivity (Hadwiger-Fangmeier et al. 1994, Aitken et al. 1984). Today 41 European countries as well as the United States and Canada participate in the ICP forest monitoring network. The ICP network provides information on the effects of air pollution on ecosystems, vegetation, fresh waters, and human health (ICP Forests 2011). There are two different types of monitoring plots within the ICP forest network, Level I and Level II.

Currently there are 6000 Level I monitoring plots and 800 Level II plots across Europe. Level I and Level II monitoring plots serve very different functions by monitoring forest condition at different intensity levels (ICP Forests 2011). The more abundant Level I monitoring plots are designed to provide an overview of forest health conditions. These sites are located on a transnational 16 x 16 km grid across Europe. The Level II monitoring plots are more intensive, designed to understand causal relationships impacting forest ecosystems and determine the effects of different stressors on forest conditions.

ICP monitoring program in the United States was initiated in 2007 with the selection of 18 experimental forests for the establishment of ICP Level II plots (ICP-II). The U.S. already had a corollary to the ICP Level I monitoring, called Forest Inventory and Analysis National Program (FIA). FIA has been compiling forest inventory / condition data since 1930 (Forest Inventory and Analysis National Program 2011). The U.S. sites, FIA plots and the newly established ICP-II plots, are managed by the Research and Development arm of the U.S. Forest Service. The addition of the ICP-II monitoring plots is an attempt at implementing the intensive monitoring established in Europe, and extending the transnational monitoring network to North America. The Sierra Ancha Experimental Forest was selected as one of the US ICP-II sites because it is the southern-most experimental forest in the United States and it is downwind from the major metropolitan area of Phoenix, Arizona.

#### SIERRA ANCHA ICP II SITE

The site is located ~40 km (~25 miles) North-Northwest of Globe, Arizona in the Sierra Ancha Mountains in the Workman Creek watershed (Figure 1). The Sierra Ancha Experimental Forest (SAEF) was established in the 1930's to study watershed management. Three watersheds that drain into Workman Creek, a perennial stream within the SAEF, were equipped with flow gauges in 1939 to study the hydrology of mixed conifer forests and the possibility of increasing water yields by manipulating forest stands

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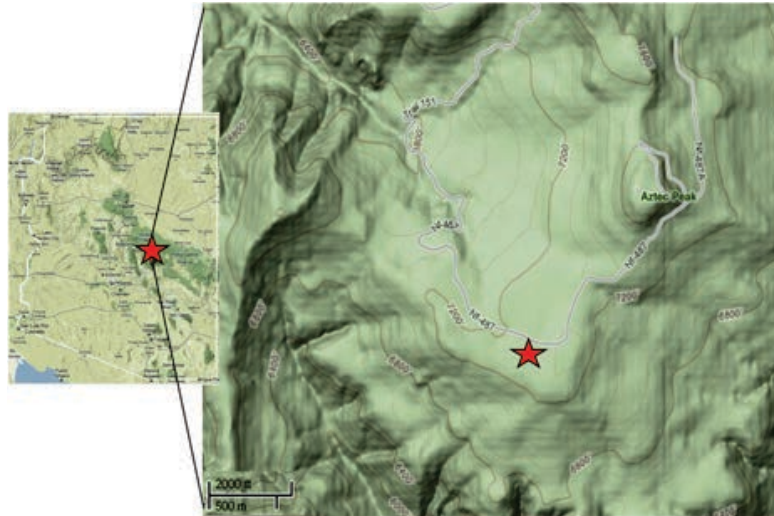


Figure 1. SAEF ICP-II site location.

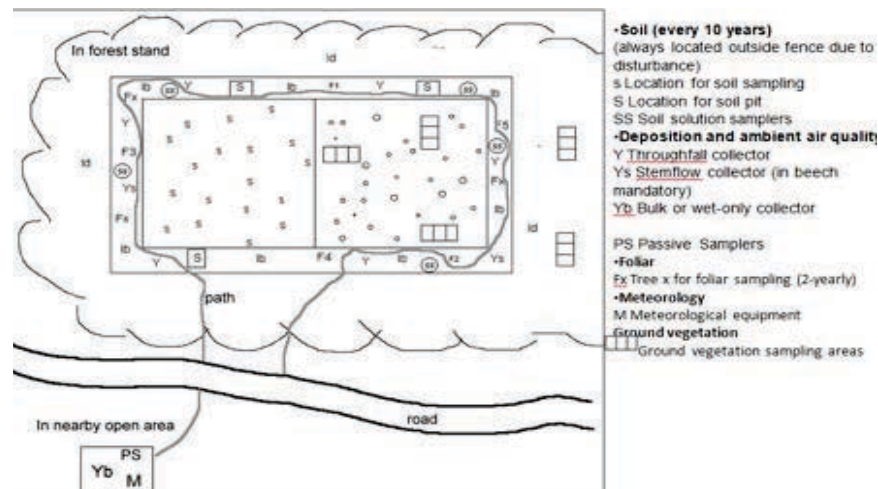


Figure 2: ICP Level II site layout with sampling type and location key.

(Rich and Gottfried 1976). These treatments were implemented between 1953 and 1969, and the study was terminated in 1980. However, following a major wildfire in 2000, the Coon Creek Fire, monitoring at Sierra Ancha was re-initiated to observe post-fire watershed responses.

The study area is situated in mountainous terrain at an elevation of approximately 2,200 m (7200 ft) on a northern aspect with a mild slope (<10%). The average annual precipitation at the site is 84 cm (33 in). The overstory is predominantly ponderosa pine (*Pinus ponderosa*); Gambel oak (*Quercus gambelii*) and New Mexican locust (*Robinia neomexicana*) are also present. The ICP-II monitoring installations are located on the

South Fork of the Workman Creek watershed which was mostly cleared during the water yield experiments (Rich and Gottfried 1976). Since then the forest has recovered and is typical of the ponderosa pine vegetation type.

## METHODS

Site selection for the ICP-II monitoring plot within the Sierra Ancha Experimentation Forest occurred in 2008. The principal requirements are an area with minimal slope, typical forest type and structure for the area, and an adjacent open area (meadow) for meteorological monitoring). In 2009, the majority of required instrumentation was purchased and site infrastructure

Table 1: ICP Level II survey frequency and completion data for the 800 sites in the European network (copied from: ICP Forests 2011, <http://www.icp-forests.org/MonLvII.htm>).

| Survey                         | Frequency                       | N. of plots             |
|--------------------------------|---------------------------------|-------------------------|
| Crown condition                | annually                        | 797                     |
| Foliar chemistry               | every 2 years                   | 767                     |
| Soil chemistry                 | every 10 years                  | 738                     |
| Tree growth                    | every 5 years                   | 769                     |
| Ground vegetation              | every 5 years                   | 723                     |
| Stand structure incl. deadwood | test phase ongoing              | 90                      |
| Epiphytic lichens              | test phase ongoing              | 90                      |
| Soil solution chemistry        | continuously                    | 254                     |
| Atmospheric deposition         | continuously                    | 545                     |
| Ambient air quality            | continuously                    | 41                      |
| Meteorology                    | continuously                    | 209                     |
| Phenology                      | several times per year          | data validation ongoing |
| Litterfall                     | continuously                    | data validation ongoing |
| Remote sensing                 | preferably at plot installation | national data           |

was installed (Figure 2). Sampling began in 2010. The crown condition survey and initial growth and yield measurements were completed. The full implementation of the ICP-II monitoring is planned to be completed during the summer and fall of 2011.

The SAEF ICP-II site uses protocols provided by the ICP forest network for both data collection and sample analysis. The principal areas of observation are vegetation, soil, and atmospheric monitoring. There are several time scales for monitoring various ecosystem properties ranging from weekly to 10 year intervals (Table 1).

### Vegetation Monitoring

Crown condition is assessed once per year on all trees over 60cm tall with less than 50% mechanical damage, such as storm or fire damage. Each assessment is made by two people facing different sides of the tree. Coppice stands are treated as a single unit. Tree crowns are assessed in two parts; the whole crown and the assessable crown. The assessable crown is the portion of the crown not affected by shading or mechanical damage. The whole crown and assessable crown are separated to differentiate between defoliation caused by direct competition and

defoliation caused by other factors such as disease and pollution. Each tree is assessed relative to a site tree; a site tree is a tree considered ideal for the site and has zero defoliation and zero discoloration. Crown condition assesses trees for foliage transparency, discoloration, extent of flowers and fruit, signs of damage, location of damage, age of damage, causes of damage and extent of damage.

Leaves from 5 trees of each major tree species are sampled every two years. Leaves are sampled and analyzed for mass, nitrogen, sulfur, potassium, calcium, magnesium, and phosphorous. Leaf samples are collected from mature leaves of the current year grown in full light. Phenological observations are made bimonthly. Both life cycle events and damaging agents are assessed. Litterfall is collected in ten 0.18 m<sup>2</sup> traps bimonthly. Leaf mass and leaf area are measured and dry weight per square meter will be calculated. Monthly carbon nitrogen, sulfur, potassium, calcium, magnesium, and phosphorous are analyzed.

Growth of all trees in the plot is measured every 5 years. The parameters measured in the growth survey are; diameter at breast height, tree height, crown height, and crown width. A survey of the ground cover is done biannually and has two purposes. The first is to characterize the current state of the forest ecosystem on the basis of the composition of the vegetation. The second is to monitor changes in the composition of the vegetation over time due to natural and anthropogenic factors. Studying vegetation dynamics aids in describing, explaining, and creating models of succession by looking at directions, reasons and methods of vegetation change (Manual 8, ICP Forests 2011). Four hundred m<sup>2</sup> are sampled to determine species cover; however, the exact size of individual sample units has not yet been determined.

### Soil Monitoring

Soil solid state measurements will be taken every 10 years. A pedagogical characterization of the soil profile will be conducted as well as sampling in a profile pit. The dry weight of the organic layer will be measured. Particle size distribution, bulk density and soil water retention characteristic will be completed for the mineral layer. Samples will be taken at 0-10cm, 10-20cm, 20-40cm, and 40-80cm. The chemical characterization will analyze; pH(H<sub>2</sub>O), pH(CaCl<sub>2</sub>+), total organic carbon, total nitrogen, carbonates, aqua regia extracted P, Ca, K, Mg, Mn, Cu, Pb, Cd, Zn, Al, Fe, Cr, Ni, S, Hg, and Na, exchangeable acidity,

exchangeable cations Ca, Mg, K, Na, Al, Fe, Mn, total elements Ca, Mg, Na, K, Al, Fe, and Mn, and oxalate extractable Fe and Al.

Soil solution, temperature, and matric potential are monitored continuously and collected biweekly. Soil solution is sampled by Prenart suction cup lysimeters which are placed at depths of 0-10 cm, 10-20 cm, 20-40 cm, and 40-80 cm. Three lysimeters are placed at each depth. The soil solution is analyzed for pH, electrical conductivity, potassium, calcium, magnesium, NO<sub>3</sub>, SO<sub>4</sub>, dissolved organic carbon, and aluminum. Soil temperature is taken at depths of 10 cm and 30 cm. Soil matric potential, which is the force needed to move water through the soil matrix, is monitored vertically from 6-30 cm in depth and horizontally at 30 cm in depth.

### Atmospheric Monitoring

Several meteorological measurements are recorded continuously from the met tower (Figure 2). These include: rainfall, wind speed, wind direction, relative humidity, air temperature, solar radiation, and photosynthetically active radiation.

Atmospheric deposition will be measured using wet deposition and throughfall (a surrogate for dry deposition). Wet deposition will be collected weekly and analyzed for calcium, magnesium, potassium, sodium, nitrate, chlorine, conductivity, pH, and sulfate using the National Atmospheric Deposition Network protocol. Throughfall will be collected by 20 throughfall collectors. Parameters to be monitored are pH, conductivity, potassium, calcium magnesium, sodium, ammonium, chlorine, nitrate, sulfate, total nitrogen, and dissolved organic carbon. Passive samplers are also being considered for use in determining atmospheric concentrations of pollutants.

Ozone will be monitored continuously from April to November. The monitor will be out of service during the winter months due to the sensitivity of the instrument and the fact that ozone levels stabilize at low levels during the winter.

### RESULTS AND DISCUSSION

Initial surveys completed on the Sierra Ancha ICP II site were crown condition and growth and yield. Overall the trees were healthy and the site classified as productive. The crowns were loosely spaced, with an average of 4.4 m of distance between crowns. The average defoliation was 16% and the average crown transparency was 57%. Overall

there was minimal damage or discoloration. Average tree height for ponderosa pines was 12.8 m and the average diameter at breast height was 31.8 cm. The tree height and DBH measurements are incomplete however due to a computer crash and loss of data. Though data collection began in 2010, the fall of 2011 is when the entire site will be considered operational.

### Challenges

There have been many challenges in implementing the ICP II forest at the Sierra Ancha Experimental Forest. Initially the permitting process for installing the fence and meteorological tower took longer than expected. Secondly, the ICP manuals that guide data collection, such as the crown condition manual, are vague, not field friendly, and are still under revision. The crown condition manual was rewritten in a bulleted and condensed format to facilitate use in the field. Thirdly, and most crucially, there is no ICP liaison to query about details where the manuals are vague or more where guidance is needed. This makes implementing the protocols detailed in the manuals difficult and reduces the value of the network overall, as different sites will undoubtedly execute unclear instructions differently. Further, there is minimal communication among U.S. sites, discrepancies on the degree of ICP-II implementation at selected experimental forests, and no direction on the required timeframe of completion. All of these issues have slowed the full completion of the Sierra Ancha Experimental Forest ICP II site. Further, the extensiveness of the ICP-II monitoring parameters is both cumbersome in field and lab time and, more importantly, requires broad expertise and dedicated funds to fully execute. This is readily apparent when viewing statistics of European ICP-II plots and survey completions (Table 1). Of the 10 required surveys there is only one, crown condition, with 100% compliance from the ~800 ICP II sites.

### CONCLUSIONS

Long-term research studies such as the ICP-II network provide invaluable information and services. The ICP II network will provide valuable air quality and air pollution effects data to land managers, and help understand regional and international trends in air quality. It will also provide important climate change information on how various forest types respond and how nutrient and pollution levels change over time. The data collected at these sites will be useful to many different researchers for many different applications. Not only is the data important, but the site itself is valuable. Long-term research sites are an anchor for other research. They provide important background and peripheral data

to other studies. There is already a decomposition study in preparation that will be placed in tandem with the SAEF ICP-II site, illustrating the utility of long-term monitoring sites. In conclusion, the ICP-II network is important in many ways and will continue to provide valuable information for years to come.

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